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ON MAGNETOSTRICTION OF GADOLINIUM IRON GARNETS

The temperature dependence of magnetostriction in the gadolinium ferrite having structure of a garnet has been measured within the temperature range from liquid nitrogen up to the Curie point. Attemperatures above the compensation point of sublattices. Θ_K the magnetostriction isotherms are of the same kind as for ferromagnetics ($\lambda_{\parallel}$ and $\lambda_{\perp}$ have opposide signs and the λ vs. H curves exhibit saturation. In cooling below there is an effect of superposition oflarge volume magnetostriction of paraprocess on the "ordinary" magnetostriction which results in the distortion of the magnetostriction isotherms ($\lambda_{\parallel}$ and $\lambda_{\perp}$ are of the same sign and without saturation). It is shown that the "ordinary" magnetostriction is due to the interaction of Fe ions in sublattices a and d, while the volume magnetostriction of the paraprocess is due to the interaction of Gd^{3+} and Fe^{3+} ions.

1. In this report we should like to point out that peculiar magnetostrictive properties of gadolinium iron garnets, which we found out in the temperature range from the liquid nitrogen up to the Curie point.

The magnetic properties of these interesting substances are known to have been studied by Pauthenet /1/, Gilleo and Geller. They have thrown light upon the character of the interaction of the magnetic sublattices in iron garnets. Here we intend to show that the investigation of the magnetostriction in the gadolinium iron garnets enables one to obtain the necessary data for finding out the details of the interaction of the sublattices in this material.

2. To study magnetostriction we prepared by the ordinary ceramic technics several samples of gadolinium ferrites. They were sufficiently large and had the following contents:

$$3Gd_2O_3 \cdot 5Fe_2O_3$$

$$3Gd_2O_3 \cdot 0{,}2Gd_2O_3 \cdot 4{,}8Fe_2O_3$$

$$3Gd_2O_3 \cdot 0{,}2Y_2O_3 \cdot 4{,}8Fe_2O_3$$

It was desirable for us to know the influence of a small change of composition on the magnetostriction.

By X-ray analysis it was ascertained that all ferrites had the structure of a garnet.

Fig. 1 shows the dependence of σ an T . The values of the Curie points Θ and the compensation points θ_K are close to the values observed by Pauthenet /1/. The magnetisation isotherms above Θ_K and below Θ_K are of entirely different character. Fig. 2 presents the magnetic hysteresis loops taken at the boiling points of nitrogen and helium. Although hysteresis is completed in relatively weak fields, there is no saturation of magnetisation on fig. 2.

To show with certainly that here we deal with paraprocess and not with the rotation of magnetisation in domains we measured the temperature dependence of magnetostriction. The magnitude of magnetostriction in the gadolinium ferrite is not large;we measured it with the aid of wire tensometers using photoelectric amplifier (FEOU-15). It was found, that at the temperatures above the compensation point (θ_K) the curves of longitudinal $\lambda_{//}$ and transversal $\lambda_{\perp}$ magnetostriction are of the same kind as for the ordinary ferromagnetics (fig.3); $\lambda_{//}$ and $\lambda_{\perp}$ have opposite signs and there is saturation on the curves (20°C). Below the compensation point (Θ_K), at the liquid nitrogen temperature, for instance, the shape of these curves changes sharply. In weak fields one can see the signs of "ordinary" magnetostriction (opposite signs of $\lambda_{//}$ and $\lambda_{\perp}$), in stronger fields however $\lambda_{//}$ and $\lambda_{\perp}$ have the same positive signs without any tendency to saturation. It is clear that in the temperature range below Θ_K we have an effect of superposition of large volume magnetostriction of paraprocess on the "ordinary" magnetostriction.

Fig. 4, 5,6 show isotherms of longitudinal magnetostriction, taken for various samples of gadolinium iron garnet with different contents. One can see that in

the temperature region above θ_K the longitudinal striction is negative and saturation takes place, when the temperature decreases below θ_K, the influence of magnetostriction of paraprocess increases and the sign of longitudinal magnetostriction becomes positive.

The value $\frac{\Delta \lambda}{\Delta H}$ - the slope of the curve in strong fields may be taken as a characteristic of magnetostriction of paraprocess. One can see on fig 7 that with decreasing temperature the value $\frac{\Delta \lambda}{\Delta H}$ increases. The increase of magnetostriction of paraprocess with the decrease of temperature is an unusual phenomenon which has not been observed before in other ferromagnetics. We know that in all ferromagnetics the paraprocess and the magnetostriction of the paraprocess increase with increasing temperature, and the value $\frac{\Delta \Delta}{\Delta H}$ reaches its maximum near the Curie point. In gadolinium ferrites the increase of $\frac{\Delta \Delta}{\Delta H}$ near the Curie point also takes place but the value of $\frac{\Delta \lambda}{\Delta H}$ is small in comparison with the value of $\frac{\Delta \lambda}{\Delta H}$ below the compensation point θ_K.

3. To understand the observed phenomenon, we shall proceed from Neel's model for iron garnets. According to this model iron garnets have 3 magnetic sublattices: c. d and a /3/. The sublattice c is formed by Gd^{3+} ions, while the sublattices d and a are formed by Fe^{3+} ions. All three sublattices interact antiferromagnetically, and according to the measured value of magnetic momenta the resultant magnetisation of these sublattices can be presented in the following way:

$$\underset{c}{\underline{\quad Gd^{3+} \quad}} \qquad \underset{d}{\underline{\quad Fe^{3+} \quad}} \qquad \underset{a}{\underline{\quad Fe^{3+} \quad}}$$

Our experiments in magnetostriction make us suppose that there is something like two ferromagnetic states in the gadolinium iron garnet. One of them is determined by the interaction of sublattices d and a (Fe^{3+} ions take part in this interaction), and the other is determined by the interaction of the sublattice c with the sublattice d and a (the interaction of the Gd^{3+} ions with

Fe^{3+}). Both these interactions originate magnetostrictions of different types. The interaction d - a (we mean magnetic dipol coupling) results in "ordinary" magnetostriction. One can provide an indirect proof of this fact by measuring magnetostriction in the yttrium iron garnet ($3Y_2O_3 \cdot 5Fe_2O_3$). If we substitute nonmagnetic Y^{3+} ions for the Gd^{3+} ions in the sublattice c only the interaction d - a will take place. The measurements of magnetostriction in the sample $3Y_2O_3 \cdot 5Fe_2O_3$ have shown that it belongs to the usual type.

The large volume magnetostriction of the paraprocess at the temperature below θ_K, we attribute to the interaction of the Gd^{3+} ions with the Fe^{3+} ions, in other words, this magnetostriction is due to the interaction of the sublattices c and d - a. The exchange interaction of the Gd^{3+} ions with the Fe^{3+} ions is small, which originates the large paraprocess. The greater are the atomic magnetic moments and the smaller is exchange interaction, the greater is the paraprocess. Under these conditions the external field will "disturb" the magnetic spin moments inside the domains with greater ease. At the same time the thermal motion will destroy the spontaneous magnetisation faster. It will cause the broadening of spontaneous magnetisation curves in such materials (curve 1 on fig. 8), as it takes place in invar alloy Ni 30 per cent Fe 70 per cent. On the contrary in the case of sublattices a - d the interaction is strong and the resultant magnetic moment is small, therefore the curve will be steeper (curve 2 on fig. 8). Taking into consideration the character of the temperature behavior of the curves, we can qualitatively explain the appearance of the compensation point θ_K in the gadolinium iron garnet. Subtracting graphically the curve 2 from the curve 1, we shall have the curve 3 with the compensation point (curve 3, fig. 8).

In this way the measuring of magnetostriction in the gadolinium iron garned makes it possible to estimate qualitatively the character and the

magnitude of the interaction of Gd^{3+} and Fe^{3+} ions and to understand the type of the dependence of the spontaneous magnetisation upon the temperature in iron garnets. Due to the large magnetostriction of paraprocess in the gadolinium iron garnet below Θ_K we are to expect great influence of pressure on the magnitude of spontaneous magnetisation. This means that the dependence of exchange interaction on the interatomic distances between the Gd^{3+} and Fe^{3+} ions is greater than the same dependence between the Fe^{3+} and Fe^{3+} ions.

4. The gadolinium iron garnets have some other peculiar features in their magnetic behaviour. Thus, for example, the coercive force greatly increases when temperature approaches Θ , and reaches its maximum at Θ_K . At first we explained the existence of this maximum H_C in a very simple way. We assumed that some structural inhomogenities in polycristalline ferrites manifests themselves in the vicinity of Θ_K . Due to this inhomogenit we can consider our sample near Θ_K consisting of a weak magnetic medium and stronger ferromagnetic areas with slightly different compensation points. This causes the appearance of monodomain structure, the processes of remagnetisation are hindered, and H_C increases. Our further measurements of temperature dependence of H_C showed, however, that actually more complex maxima (double maxima - fig. 9) are to be found in the neighborhood of Θ_K in most cases. Both maxima are situated close to each other, but on the opposite sides of Θ_K . So far we cannot offer an exhaustive interpretation of the observed phenomenon. It is possible that the two above mentioned ferromagnetic states (the interaction of the ions Gd^{3+} - Fe^{3+} and Fe^{3+} - Fe^{3+}) are responsible for the appearance of the double maxima .

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28.10.1959

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(Pedko, A. V.)

The Explanatory Texts to the Diagrams

Fig. The dependence of the spontaneous magnetisation on temperature in gadolinium iron garnets: 1. $3Gd_2O_3.5Fe_2O_3$; 2. $3\ Gd_2O_3.0,2Gd_2O_3.4,8Fe_2O_3$; 3. $3Gd_2O_3.0.2Y_2O_3.4,8Fe_2O_3$

Fig. 2. Hysteresis loops of the gadolinium iron garnet at low temperatures.

Fig. 3. Transversal and longitudinal magnetostriction for the ferrite $3Gd_2O_3.0,2Gd_2O_3.4,8Fe_2O_3$ at the room temperature and the liquid nitrogen temperature.

Fig. 4. Isotherms of the longitudinal magnetostriction of the ferrite $3Gd_2O_3.0,2Gd_2O_3.4,\ 8Fe_2O_3$ above the compensation point.

Fig. 5. Isotherms of the longitudinal magnetostriction of the ferrite $3Gd_2O_3.0,2Gd_2O_3.4,\ 8Fe_2O_3$ below and above the compensation point.

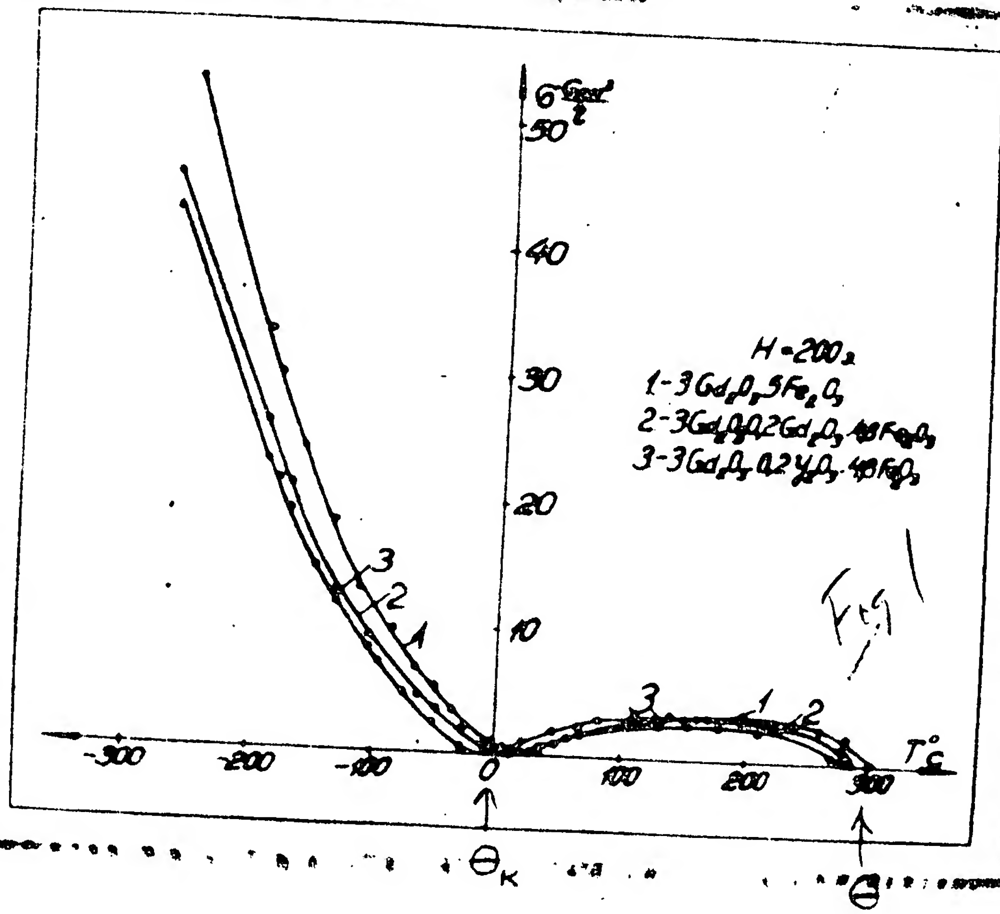
Fig. 6. Isotherms similar to those in fig. 5., only for the ferrite $3Gd_2O_3.5Fe_2O_3$.

Fig. 7. The dependence of the value $\frac{\Delta\lambda}{\Delta H}$ on temperatures for:

1. $3Gd_2O_3.5Fe_2O_3$.
2. $3Gd_2O_3.0,2Gd_2O_3.4,\ 8Fe_2O_3$.
3. $3Gd_2O_3.0,2Y_2O_3.4,8Fe_2O_3$.

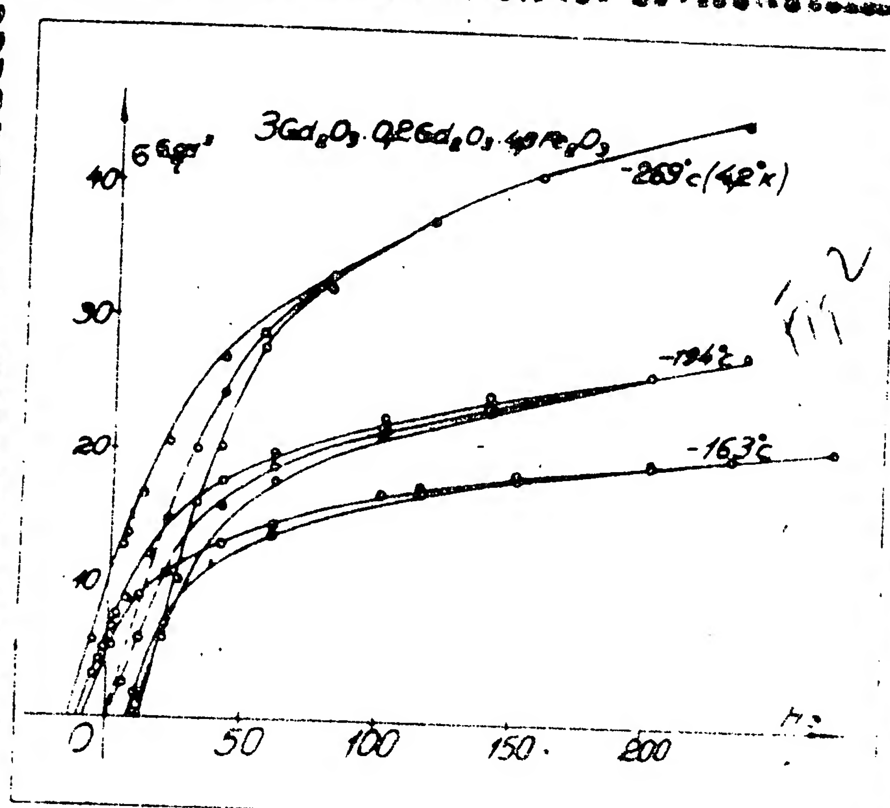
Fig. 8. To the explanation of the temperature dependence of the spontaneous magnetisation of the gadolinium iron garnet.

Fig. 9. The temperature dependence of the coercive force in the ferrite $3Gd_2O_3.0,2Gd_2O_3.4,8Fe_2O_3$.



σ Gcm³/g
50
40
30
20
10
H = 200 э
1 - 3Gd₂O₃ 5Fe₂O₃
2 - 3Gd₂O₃ 0.2Gd₂O₃ 4.8Fe₂O₃
3 - 3Gd₂O₃ 0.2Y₂O₃ 4.8Fe₂O₃
-300
-200
-100
0
100
200
300
T°C
Θ_K
Θ

Fig 1



σ Gcm³/g
3Gd₂O₃ 0.2Gd₂O₃ 4.8Fe₂O₃
40
30
20
10
-269°c (4.2°K)
-196°c
-16.3°c
0
50
100
150
200
H э

Fig 2

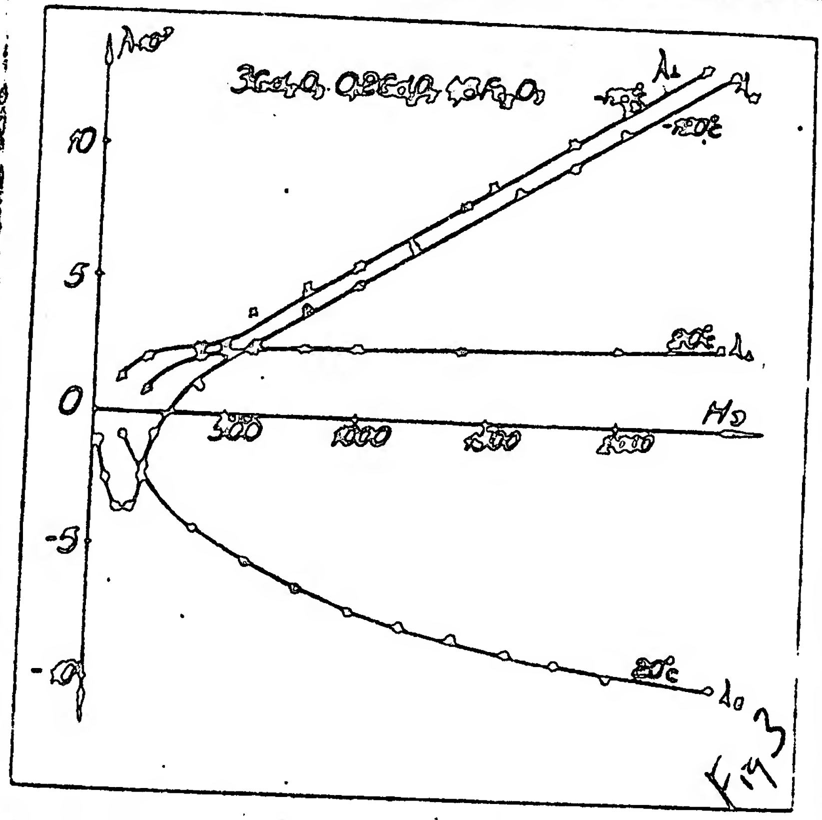

λ·10⁶
10
5
0
-5
-10
500
1000
1500
2000
Hэ
20°C
λ₁
λ₀

Fig 3

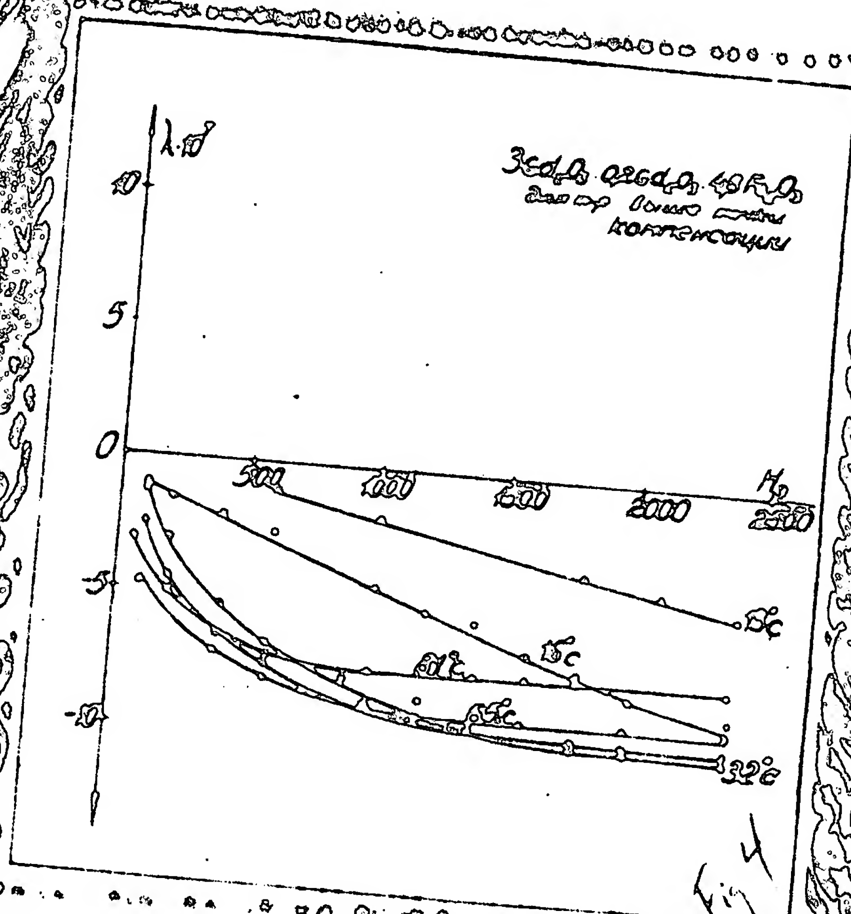

λ·10⁶
10
5
0
-5
-10
500
1000
1500
2000
2500
Hэ
15°C
32°C

Fig 4

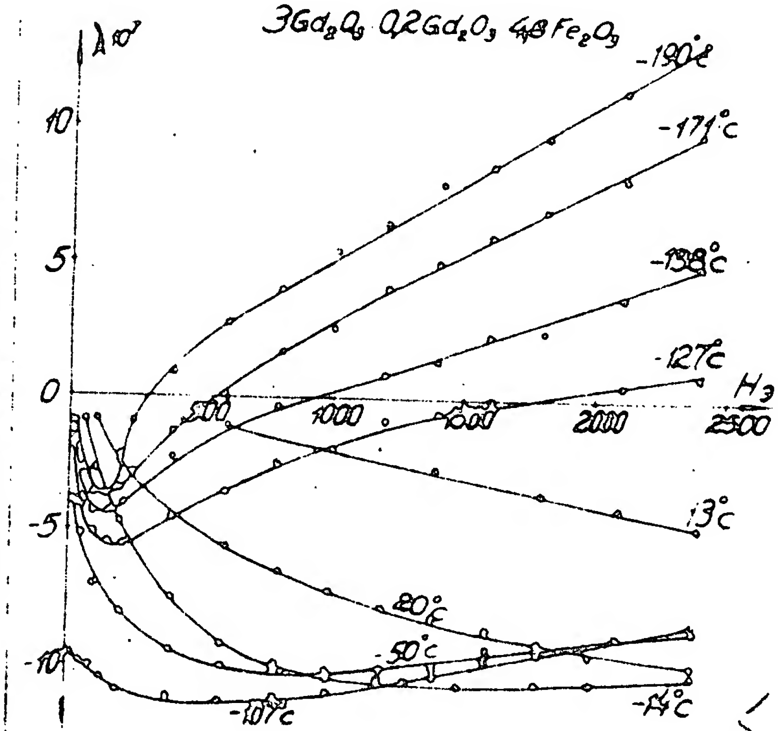

$\lambda \cdot 10^7$
3Gd2O3 · 0,2Gd2O3 · 4,8Fe2O3
-190°C
-171°C
-138°C
-127°C
13°C
20°C
-50°C
-107°C
-14°C
10
5
0
-5
-10
500
1000
1500
2000
2500
Hэ

Fig 5

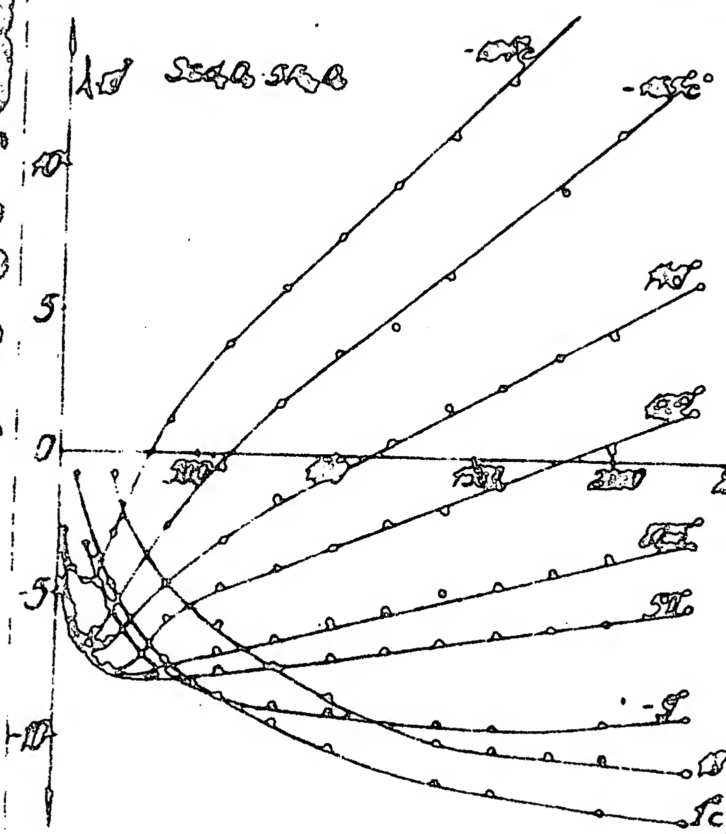

$\lambda \cdot 10^7$
10
5
0
-5
-10
5°C

Fig 6

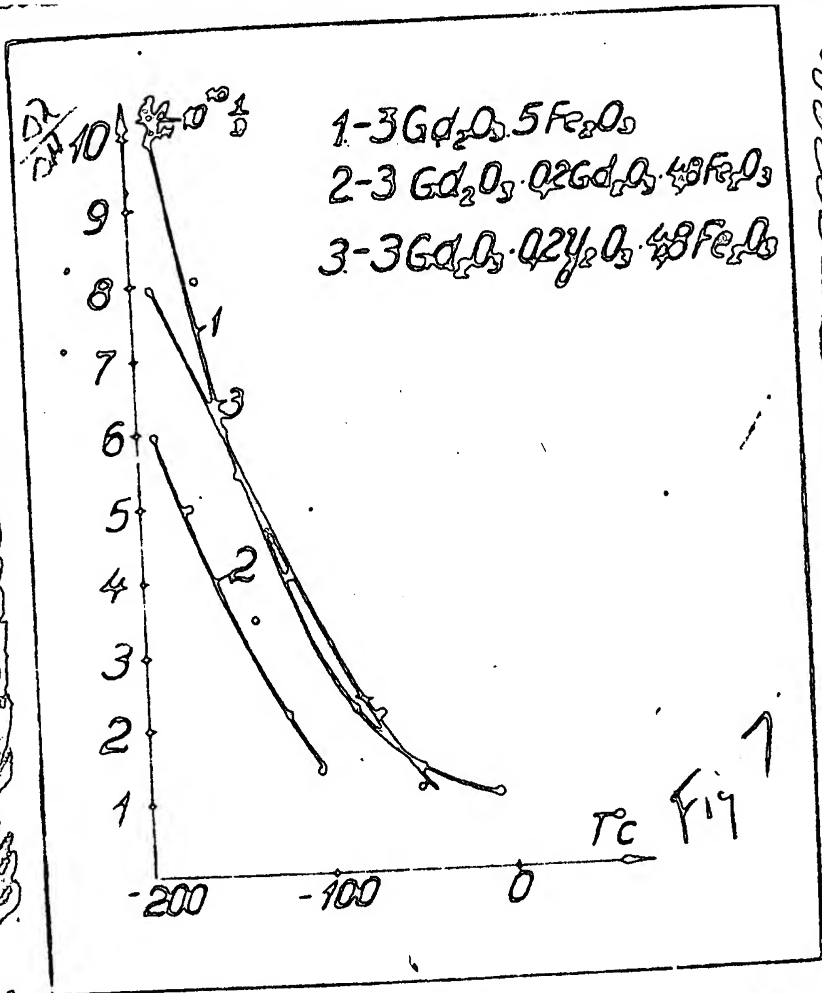


Fig 1

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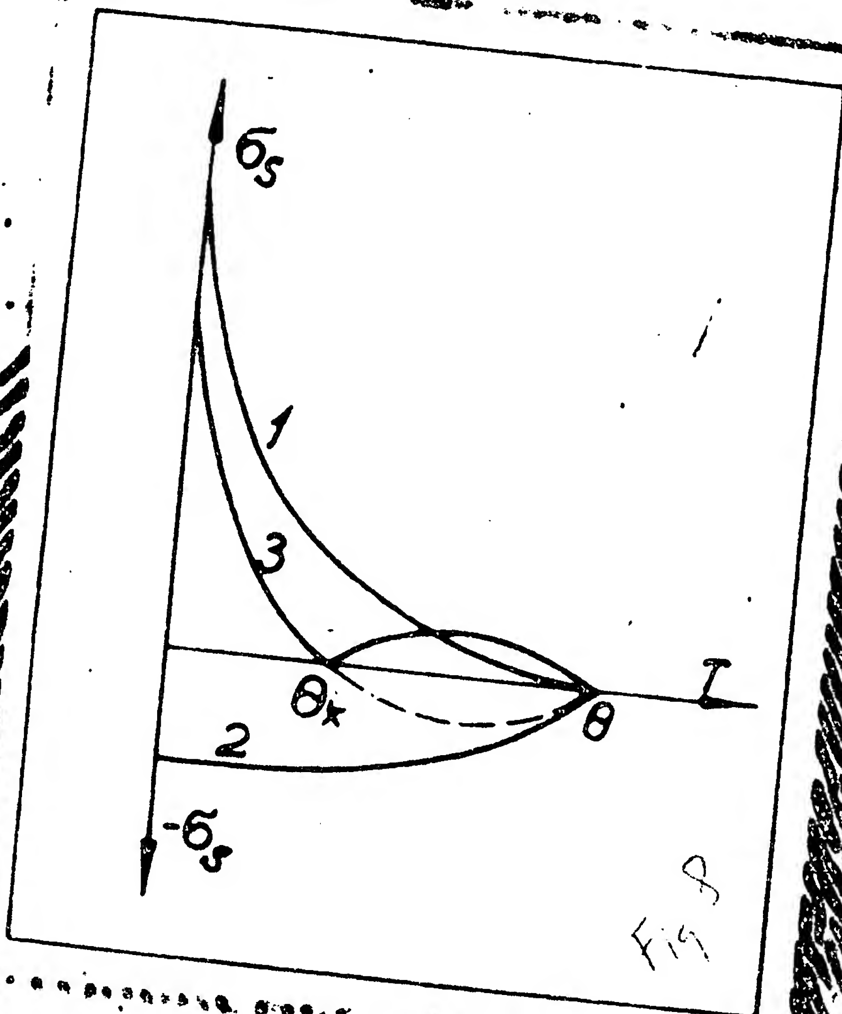

Fig 8

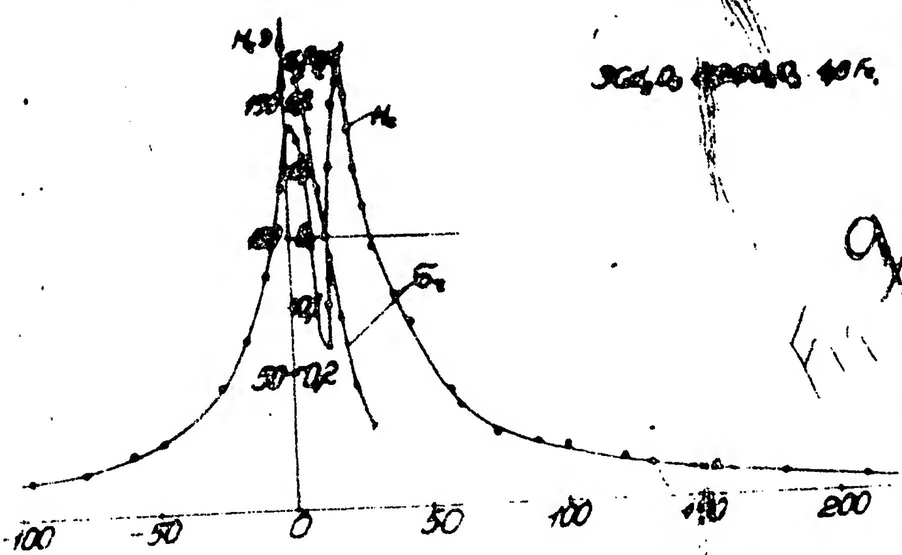

Fig 9

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